

Attachment 2

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November 27, 1963

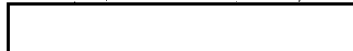
AERODYNAMICALLY HEATED WINDOW BEHAVIOR

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by

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ACKNOWLEDGMENT

For classification reasons, this report was authored by
[redacted] Most of the work contained herein, however,
was performed on a "sterilized" basis by [redacted]
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SUMMARY

STAT This report presents the results of a 4 week study of the behavior of an aerodynamically heated window for [] STAT
[] The study revealed that the double paned window will retain its integrity and not distort sufficiently to influence its optical quality. The inner window surface will operate at about 325° F and will radiate 446 Btu/hr-ft² into the instrument compartment. Results of a literature search on the optical and radiation characteristics of thinly gold-plated glass are also included herein.

AERODYNAMICALLY HEATED WINDOW BEHAVIOR

1. INTRODUCTION

According to the work statement of October 11, 1963, [] was authorized to perform the following tasks:

- a. Compute the thermal load and temperature distribution through a specified window design for conditions transmitted verbally to [] on October 8, 1963.
- b. Carry out a literature survey to determine characteristics of a specified gold coating and to estimate its thermal effect.

The schedule for the above activity called for preliminary comments to be supplied by November 4, 1963 and a final report by November 11, 1963. A report of the final results was delivered verbally by the author to [] and [] on November 5, 1963. This follow-on report is to provide a permanent record of the results of this investigation.

2. SPECIFIED WINDOW DESIGN AND FLIGHT CONDITIONS

The window design considered in the current study is a window composed of two panes separated by a gap. The outer pane is made of Quartz (SiO_2) and the inner pane of Schott BK-7. Both panes are 0.400-inch thick and are taken to be 11.53 inches along the axis of the aircraft and 17.97 inches in the span direction. A gap thickness of 0.08 inch was considered as the nominal gap dimension. The window was assumed to be mounted flush with the outer skin of the aircraft. In the absence of any information regarding the thermal boundary condition on the inner portion of the skin, no consideration has been made of the possible effects caused by the window outer surface being at a different temperature than the upstream skin.

The thermal behavior of the window was studied for the case where the window is mounted on the lower surface of an aircraft flying at a Mach number of 3.2 at an altitude of 85,000 feet. The leading edge of the window was located at station 720 of the aircraft. The aircraft bottom was assumed to behave as a flat plate at an angle of attack of 7° .

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3. EXTERNAL FLOW CONDITIONS AND AERODYNAMIC HEATING RATE

At an altitude of 85,000 feet the local atmospheric conditions are as follows:

temperature, $T_{\infty} = 394^{\circ} \text{ R}$
 pressure, $p_{\infty} = 4.6 \text{ lb/ft}^2 = 0.0218 \text{ atm}$
 velocity of sound, $a_{\infty} = 972 \text{ ft/sec}$
 density, $\bar{\rho}_{\infty} = 6.8 \times 10^{-5} \text{ lb sec}^2/(\text{ft})^4$
 velocity, $u_{\infty} = 3.11 \times 10^3 \text{ ft/sec}$

The compression that takes place in the shock wave ahead of the plate at 7° angle of attack alters these conditions at the edge of the boundary layer over the window to be as follows:

temperature, $T_{\delta} = 467^{\circ} \text{ R}$
 pressure, $p_{\delta} = 0.0372 \text{ atm}$
 velocity, $u_{\delta} = 2.975 \times 10^3 \text{ ft/sec}$

For these local conditions, the convective heat flux to the window can be expressed as

$$q = C_H c_p (T_r - T_e) \quad (1)$$

where

C_H convective heating coefficient

$$\frac{38.5}{\left(\frac{T^1}{T_{\delta}}\right)^{0.84}} \quad (2)$$

C_p specific heat of air, $0.24 \text{ Btu/lb } ^{\circ}\text{R}$

T_r recovery temperature

$$T_{\delta} + r \frac{u_{\delta}^2}{2g J C_p} = 467 + 667 = 1134^{\circ} \text{ R} \quad (3)$$

T_e outer window temperature

T^1 reference temperature at which to evaluate properties

$$T_{\delta}^1 = 2003/02/27 \text{ CIA-RDP81B00875R001000130064-1} \quad (4)$$

From Equations (2) and (4), it can be observed that C_H is dependent on T_e and therefore Equation (1) is nonlinear. The manner of solution was to assume a reasonable value of T_e in Equation (4), solve for the surface temperature, and to iterate until convergence occurred. Only two steps were usually needed in this iteration process. Note that T_e in the temperature potential term does not have to be prescribed initially in that it is obtained explicitly in the solution of the heat balance equations for the window.

4. HEAT BALANCE ON THE WINDOW

The heat balance performed on the window is indicated schematically in Figure 1. The assumptions employed in this heat balance are as follows:

- a. Steady-state, the windows are exposed sufficiently long to be at equilibrium.
- b. All heat flow is unidirectional.
- c. The air in the gap between the windows is stagnant.
- d. Convection patterns over the inner surface of the window are uniform.

The symbols employed in the heat balance are indicated in Figure 1 and are defined generally as follows:

T	temperature, °R
ϵ	emissivity expressed as a function of the glass temperatures
σ	Stefan-Boltzmann constant
k	thermal conductivity of the glasses as a function of average temperature of the windows
l	width of window or gap
h_i	convective heat-transfer coefficient on the inside of the window introduced by free convection or internal blowing
T_s	internal cooling air temperature
T_4	internal mean surface temperatures

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A balance on the heat flux in and out of each surface yields four simultaneous equations that can be solved for the four unknown temperatures T_6 , T_7 , T_9 , and T_{10} .

5. DISCUSSION OF RESULTS

For all the computations presented here, it was assumed that the internal air passing over the window and the interior surfaces were maintained at 70°F or 530°R .

The first effect studied was that introduced by varying the internal convective heat-transfer coefficient. It was estimated that the expected elevated window temperature and its nearly horizontal position at the bottom of the cavity would cause free convection and an internal heat-transfer coefficient of about $0.25\text{ Btu/hr-ft}^2\text{ }^\circ\text{F}$. Because this value could be diminished by configuration effects if the window is recessed, it was decided to run calculations for an internal heat-transfer coefficient ranging from half the expected free-convection coefficient to ten times this value. The increased heat-transfer coefficient can be caused by air circulation fans. For the nominal internal free-convection conditions, the following results were obtained

outer window, exterior temperature	446°F
outer window, gap-side temperature	428°F
inner window, gap-side temperature	349°F
inner window, inside temperature	325°F
radiation heat flux to instrument	446 Btu/hr-ft^2
total heat flux to instrument	509 Btu/hr-ft^2

These temperatures are well within the useful ranges of the glasses considered.

The effect of varying the internal heat-transfer coefficient is shown in Figure 2. In this figure the inner window inside temperature, and the heat load to the instrument compartment are shown as functions of the inside heat-transfer coefficient. This figure indicates that a ten-fold increase of the internal convection coefficient can cause a sizeable reduction in the internal surface temperature, approximately 80°F , but this also increases the amount of heat transferred to the camera compartment by about 40 percent. The 80°F change in temperature reduces the radiant heat flux from the window by 41 percent. The largest increase shown in the internal convective coefficient only causes about a 25°F reduction in the external window temperature; therefore, increasing the internal convective coefficient will not alter the strength of the window significantly. The main advantage of lowering the inner window temperature is the reduction of heat flux radiated from the window to the lens, rather than structural heating of the window. Lowering this heat flux and increasing the air turbulence in the light path from an

optical viewpoint, however, will require careful study in the development of the current system.

Another means was considered for reducing the window inner temperature. This consisted of applying an optically semi-transparent film of gold on one of the four window surfaces. The gold film characteristics used in this study were obtained in a literature survey that is described in the next section of this report. A conservative figure of 0.08 was used for the gold film emissivity and the results of this study are shown in Table I. The nominal condition in the absence of any gold is also shown for reference. The following observations can be deduced from the table:

- a. Placing the gold on the exterior surface of the window, 6 of Table I, causes a rise in temperature of both panes. The reason for this is the reduction of the heat rejected by radiation to space by the window because of the low emissivity of the gold. Under this condition both the radiated and total heat load into the camera compartment are increased.
- b. Placing the gold on either of the inner gap surfaces, 7 or 9 of Table I, produces an identical effect. It increases the outer window temperature slightly above the nominal case, and reduces the inner window temperature. The radiation from the inner window is reduced about 16 percent and the total heat load is also reduced.
- c. Placing the gold on the interior surface, 10 of Table I, blocks the heat from entering the camera cavity and consequently causes both window temperatures to rise. The rise in temperature of the inner surface, however, does not compensate for the reduction of the emissivity of the gold, and the heat flux radiated toward the lens is only 18 percent of the nominal case. Another advantage of this case is the reduction of the temperature gradients within the glass plates and, consequently, reduced bending.

Deflection calculations were performed under the assumption of unrestrained edges. The deflections at a radius of 6 inches from the center of the window, for the nominal temperature conditions, were 108λ and 226λ in the outer and inner windows, respectively ($\lambda = 0.56\mu$).

6. SUMMARY OF LITERATURE SURVEY

A literature survey was conducted on the subjects of the transmittance, absorptivity, and reflectivity of metallic gold. Approved For Release 2003/02/27 : CIA-RDP81B00870R001000130064-1 University

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STAT Library, [] and the library at Lockheed Missiles and Space Company, Sunnyvale, provided the basic sources of open available technical information related to the transmittance, absorptivity, and reflectivity of metallic gold films on glass.

References 1 to 6 list the major journals reviewed in this survey; the results of which are rather unproductive. References 7 to 13 were found in these journals which are related to the subject area but all failed to provide information applicable to this specific subject.

The Armed Services Technical Information Agency (ASTIA) performed a literature search, in conjunction with our request, on this subject area. The results of this search listed approximately 300 references, all of which related in some way to the subject area but none appeared to be applicable to our specific problem except those already obtained from the other mentioned sources.

STAT References 14 to 22 are related reports presently available in [] However, none of these except Turner's paper (Ref. 22) [] specifically discusses metallic gold films. STAT

The most comprehensive source on the subject is Heavens' book "Optical Properties of Thin Solid Films" (Ref. 23). It appears that this book presents the most complete analysis of the technological aspects of thin film optics available.

The most pertinent paper; however, remains Turner's paper (Ref. 22). Unfortunately, the application of Turner's data raises almost as many questions as it answers. The major disadvantage to Turner's paper for the present problem is due to the wavelength region currently considered. Other factors, such as the rate of disposition, method of application, and complete definition of curves, tends to add confusion.

In spite of various problems, Heaven's book and Turner's paper (Refs. 23 and 22) were the best references found in the process of this literature search.

The one company that has apparently issued the greatest number of reports in the subject area is the Bausch and Lomb Optical Company of Rochester, New York. Published reports indicate that this company has been actively engaged in experimental and theoretical research in this area at least for the past 15 years. The next step in this literature search should definitely be centered toward communications with this company.

The following references are presented as references pertaining to the general area, but very few deal with the specifics desired.

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TABLE I.- EFFECT OF GOLD FILM ON ONE OF THE WINDOW SURFACES.

	<div style="display: flex; align-items: center; justify-content: space-around;"> <div style="text-align: center;"> ⁶ exterior </div> <div style="border-left: 1px solid black; border-right: 1px solid black; height: 100px; width: 100px; position: relative;"> <div center;"="" style="position: absolute; top: 0; left: 0; right: 0; height: 100%; background: repeating-linear-gradient(45deg, transparent, transparent 2px, black 2px, black 4px);</div> </div> <div style=" text-align:=""> ⁷ ⁹ ¹⁰ </div> <div style="text-align: center;"> interior </div> </div> </div>					
Location of gold foil	T_6 °F	T_7 °F	T_9 °F	T_{10} °F	Q_{rad} Btu/hr-ft	Q_{load} Btu/hr-ft ²
none	445.6	427.9	348.9	324.6	446	509
6	539.7	516.0	420.6	387.5	636	715
7	452.9	437.8	319.0	298.0	377	424
9	452.9	437.8	319.0	298.0	377	424
10	477.4	471.5	448.3	440.4	79	171

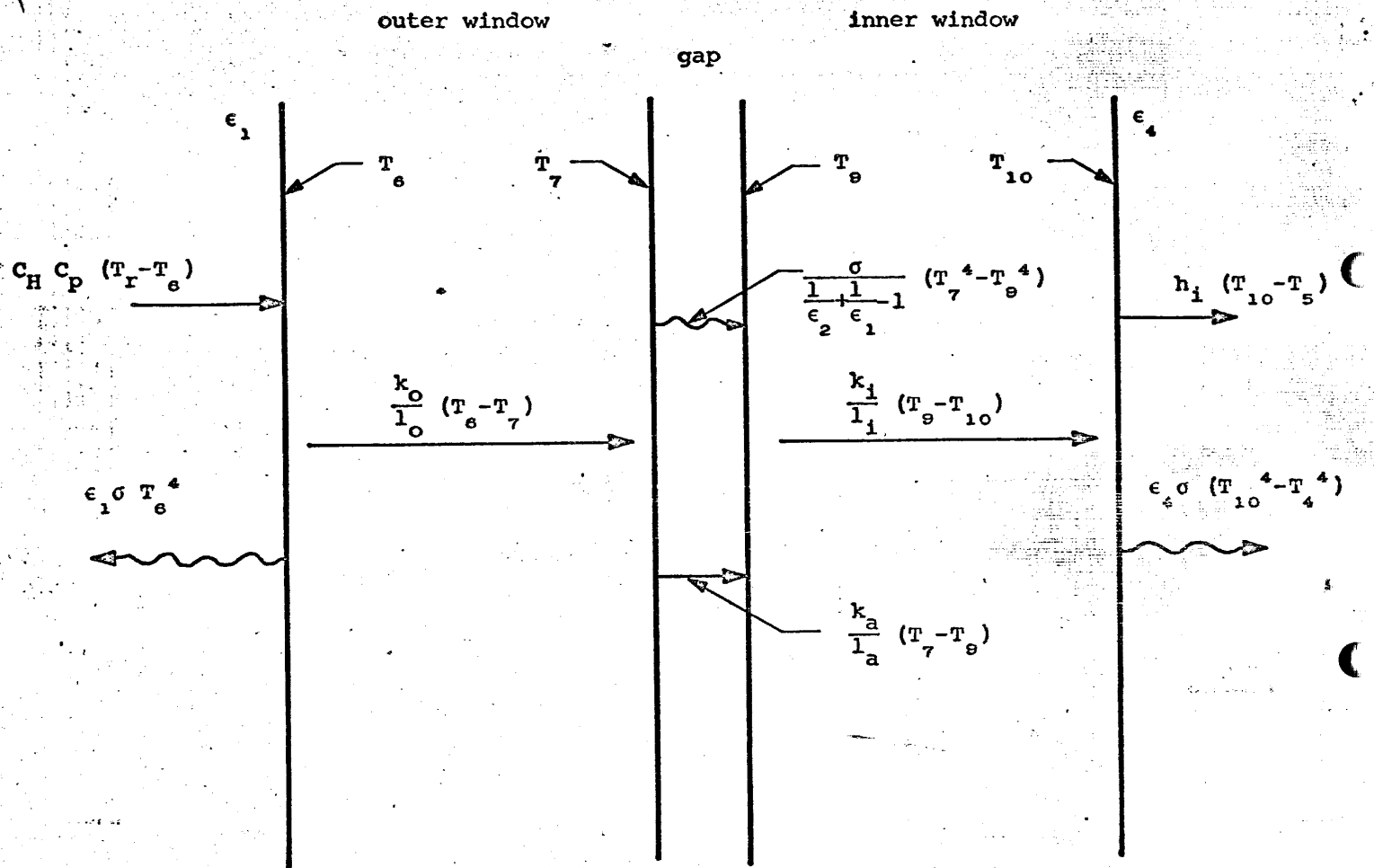


Figure 1.- Schematic diagram of heat balance employed on window.

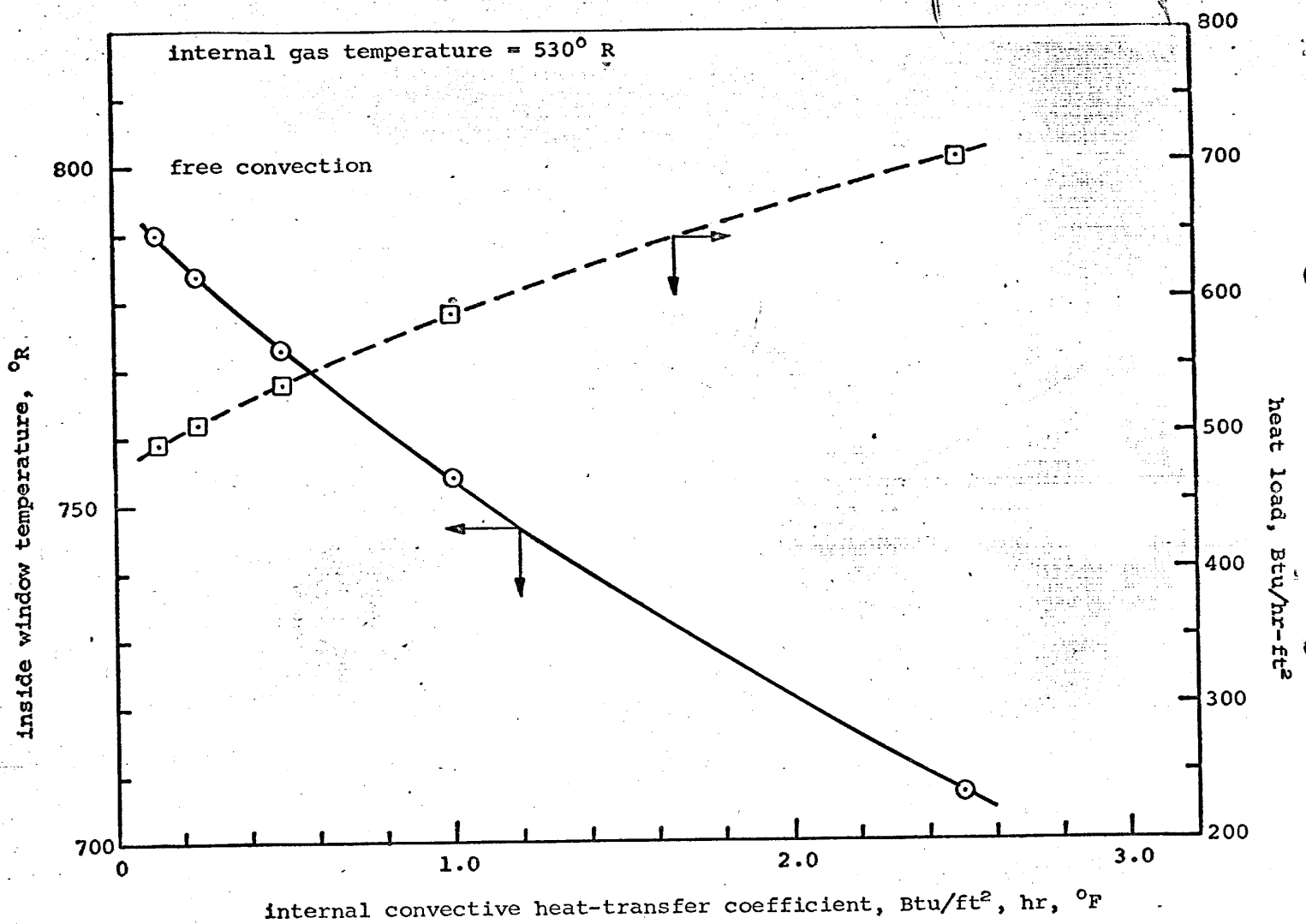


Figure 2.- Effect of internal convective heat-transfer coefficient on inside temperature and heat load.